

ORGANOPHOTORECEPTOR WITH CHARGE TRANSPORT COMPOUND WITH AN AZINE GROUP

FIELD OF THE INVENTION

5 This invention relates to organophotoreceptors suitable for use in electrophotography and, more specifically, to organophotoreceptors having an improved charge transport compound with at least two azine groups.

BACKGROUND OF THE INVENTION

10 In electrophotography, an organophotoreceptor in the form of a plate, disk, sheet, belt, drum or the like having an electrically insulating photoconductive element on an electrically conductive substrate is imaged by first uniformly electrostatically charging the surface of the photoconductive layer, and then exposing the charged surface to a pattern of light. The light exposure selectively dissipates the charge in the illuminated 15 areas where light strikes the surface, thereby forming a pattern of charged and uncharged areas, referred to as a latent image. A liquid or solid toner is then provided in the vicinity of the latent image, and toner droplets or particles deposit in the vicinity of either the charged or uncharged areas to create a toned image on the surface of the photoconductive layer. The resulting toned image can be transferred to a suitable ultimate or intermediate 20 receiving surface, such as paper, or the photoconductive layer can operate as an ultimate receptor for the image. The imaging process can be repeated many times to complete a single image, for example, by overlaying images of distinct color components or effect shadow images, such as overlaying images of distinct colors to form a full color final image, and/or to reproduce additional images.

25 Both single layer and multilayer photoconductive elements have been used. In single layer embodiments, a charge transport material and charge generating material are combined with a polymeric binder and then deposited on the electrically conductive substrate. In multilayer embodiments, the charge transport material and charge generating material are present in the element in separate layers, each of which can 30 optionally be combined with a polymeric binder, deposited on the electrically conductive substrate. Two arrangements are possible. In one two-layer arrangement (the "dual

layer" arrangement), the charge-generating layer is deposited on the electrically conductive substrate and the charge transport layer is deposited on top of the charge generating layer. In an alternate two-layer arrangement (the "inverted dual layer" arrangement), the order of the charge transport layer and charge generating layer is reversed.

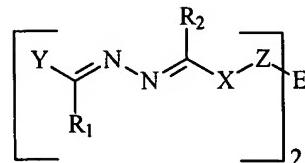
In both the single and multilayer photoconductive elements, the purpose of the charge generating material is to generate charge carriers (i.e., holes and/or electrons) upon exposure to light. The purpose of the charge transport material is to accept at least one type of these charge carriers, generally holes, and transport them through the charge transport layer in order to facilitate discharge of a surface charge on the photoconductive element. The charge transport material can be a charge transport compound, an electron transport compound, or a combination of both. When a charge transport compound is used, the charge transport compound accepts the hole carriers and transports them through the layer with the charge transport compound. When an electron transport compound is used, the electron transport compound accepts the electron carriers and transports them through the layer with the electron transport compound.

SUMMARY OF THE INVENTION

This invention provides organophotoreceptors having good electrostatic properties such as high V_{acc} and low V_{dis} .

In a first aspect, an organophotoreceptor comprises an electrically conductive substrate and a photoconductive element on the electrically conductive substrate, the photoconductive element comprising:

- (a) a charge transport compound having the formula



where R_1 and R_2 are, independently, hydrogen, an alkyl group, an alkaryl group or an aryl group; X is an aromatic group; Y is an (N,N -disubstituted)arylamine; Z is $(CH_2)_m$ group where m is an integer between 0 and 30 where one or more of the methylene groups is

optionally replaced by O, S, C=O, O=C-O, O=C-NR₃, sulfoxide, sulfate, phosphate, an aryl group, urethane, urea, NR₄ group, CHR₅ group, or CR₆R₇ group where R₃, R₄, R₅, R₆, and R₇ are, independently, H, hydroxyl, thiol, an amine group, an alkyl group, an alkaryl group, a heterocyclic group, or an aryl group, and E is a bond, O, S, C=O, NR₈, CR₉R₁₀ group, a heterocyclic group, or an aromatic group where R₈, R₉, and R₁₀ are, independently, H, an alkyl group, an alkaryl group, or an aryl group; and
5 (b) a charge generating compound.

The organophotoreceptor may be provided, for example, in the form of a plate, a flexible belt, a flexible disk, a sheet, a rigid drum, or a sheet around a rigid or compliant drum. In one embodiment, the organophotoreceptor includes: (a) a photoconductive element comprising the charge transport compound, the charge generating compound, the electron transport compound, and a polymeric binder; and (b) the electrically conductive substrate.
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In a second aspect, the invention features an electrophotographic imaging apparatus that comprises (a) a light imaging component; and (b) the above-described organophotoreceptor oriented to receive light from the light imaging component. The apparatus can further comprise a liquid toner dispenser. The method of electrophotographic imaging with photoreceptors containing the above noted charge transport compounds is also described.
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20 In a third aspect, the invention features an electrophotographic imaging process that includes (a) applying an electrical charge to a surface of the above-described organophotoreceptor; (b) imagewise exposing the surface of the organophotoreceptor to radiation to dissipate charge in selected areas and thereby form a pattern of at least relatively charged and uncharged areas on the surface; (c) contacting the surface with a toner, such as a liquid toner that includes a dispersion of colorant particles in an organic liquid, to create a toned image; and (d) transferring the toned image to a substrate.
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In a fourth aspect, the invention features a charge transport compound having the general formula (1) above.

The invention provides suitable charge transport compounds for organophotoreceptors featuring a combination of good mechanical and electrostatic properties. These photoreceptors can be used successfully with liquid toners to produce
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high quality images. The high quality of the imaging system can be maintained after repeated cycling.

Other features and advantages of the invention will be apparent from the following description of the particular embodiments thereof, and from the claims.

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DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

An organophotoreceptor as described herein has an electrically conductive substrate and a photoconductive element comprising a charge generating compound and a charge transport compound having two azine groups linked through two aromatic groups.

10 These charge transport compounds have desirable properties as evidenced by their performance in organophotoreceptors for electrophotography. In particular, the charge transport compounds of this invention have high charge carrier mobilities and good compatibility with various binder materials, can be cross-linked in both the single and multilayer photoconductive elements, and possess excellent electrophotographic properties. The organophotoreceptors according to this invention generally have a high photosensitivity, a low residual potential, and a high stability with respect to cycle testing, crystallization, and organophotoreceptor bending and stretching. The organophotoreceptors are particularly useful in laser printers and the like as well as photocopiers, scanners and other electronic devices based on electrophotography. The 15 use of these charge transport compounds is described in more detail below in the context of laser printer use, although their application in other devices operating by electrophotography can be generalized from the discussion below.

To produce high quality images, particularly after multiple cycles, it is desirable for the charge transport compounds to form a homogeneous solution with the polymeric 20 binder and remain approximately homogeneously distributed through the organophotoreceptor material during the cycling of the material. In addition, it is desirable to increase the amount of charge that the charge transport material, such as a charge transport compound, can accept (indicated by a parameter known as the acceptance voltage or " V_{acc} "), and to reduce retention of that charge upon discharge 25 (indicated by a parameter known as the discharge voltage or " V_{dis} ").

There are many charge transport compounds available for electrophotography. Examples of charge transport compounds include, for example, pyrazoline derivatives, fluorene derivatives, oxadiazole derivatives, stilbene derivatives, hydrazone derivatives, carbazole hydrazone derivatives, triaryl amines, polyvinyl carbazole, polyvinyl pyrene, 5 polyacenaphthylene, or multi-hydrazone compounds comprising at least two hydrazone groups and at least two groups selected from the group consisting of p-(N,N-disubstituted) arylamine such as triphenylamine and heterocycles such as carbazole, julolidine, phenothiazine, phenazine, phenoxazine, phenoxathiin, thiazole, oxazole, isoxazole, dibenzo(1,4)dioxine, thianthrene, imidazole, benzothiazole, benzotriazole, 10 benzoxazole, benzimidazole, quinoline, isoquinoline, quinoxaline, indole, indazole, pyrrole, purine, pyridine, pyridazine, pyrimidine, pyrazine, triazole, oxadiazole, tetrazole, thiadiazole, benzisoxazole, benzisothiazole, dibenzofuran, dibenzothiophene, thiophene, thianaphthene, quinazoline, or cinnoline. However, there is a need for other charge 15 transport compounds to meet the various requirements of particular electrophotography applications.

In electrophotography applications, a charge-generating compound within an organophotoreceptor absorbs light to form electron-hole pairs. These electron-hole pairs can be transported over an appropriate time frame under a large electric field to discharge locally a surface charge that is generating the field. The discharge of the field at a 20 particular location results in a surface charge pattern that essentially matches the pattern drawn with the light. This charge pattern then can be used to guide toner deposition. The charge transport compounds described herein are especially effective at transporting charge, and in particular holes from the electron-hole pairs formed by the charge generating compound. In some embodiments, a specific electron transport compound can 25 also be used along with the charge transport compound.

The layer or layers of materials containing the charge generating compound and the charge transport compounds are within an organophotoreceptor. To print a two dimensional image using the organophotoreceptor, the organophotoreceptor has a two dimensional surface for forming at least a portion of the image. The imaging process 30 then continues by cycling the organophotoreceptor to complete the formation of the entire image and/or for the processing of subsequent images.

The organophotoreceptor may be provided in the form of a plate, a flexible belt, a disk, a rigid drum, a sheet around a rigid or compliant drum, or the like. The charge transport compound can be in the same layer as the charge generating compound and/or in a different layer from the charge generating compound. Additional layers can be used 5 also, as described further below.

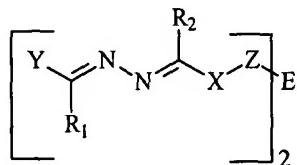
In some embodiments, the organophotoreceptor material comprises, for example: (a) a charge transport layer comprising the charge transport compound and a polymeric binder; (b) a charge generating layer comprising the charge generating compound and a polymeric binder; and (c) the electrically conductive substrate. The charge transport 10 layer may be intermediate between the charge generating layer and the electrically conductive substrate. Alternatively, the charge generating layer may be intermediate between the charge transport layer and the electrically conductive substrate. In further embodiments, the organophotoreceptor material has a single layer with both a charge transport compound and a charge generating compound within a polymeric binder.

15 The organophotoreceptors can be incorporated into an electrophotographic imaging apparatus, such as laser printers. In these devices, an image is formed from physical embodiments and converted to a light image that is scanned onto the organophotoreceptor to form a surface latent image. The surface latent image can be used to attract toner onto the surface of the organophotoreceptor, in which the toner 20 image is the same or the negative of the light image projected onto the organophotoreceptor. The toner can be a liquid toner or a dry toner. The toner is subsequently transferred, from the surface of the organophotoreceptor, to a receiving surface, such as a sheet of paper. After the transfer of the toner, the entire surface is discharged, and the material is ready to cycle again. The imaging apparatus can further 25 comprise, for example, a plurality of support rollers for transporting a paper receiving medium and/or for movement of the photoreceptor, a light imaging component with suitable optics to form the light image, a light source, such as a laser, a toner source and delivery system and an appropriate control system.

An electrophotographic imaging process generally can comprise (a) applying an 30 electrical charge to a surface of the above-described organophotoreceptor; (b) imagewise exposing the surface of the organophotoreceptor to radiation to dissipate charge in

selected areas and thereby form a pattern of charged and uncharged areas on the surface; (c) exposing the surface with a toner, such as a liquid toner that includes a dispersion of colorant particles in an organic liquid to create a toner image, to attract toner to the charged or discharged regions of the organophotoreceptor; and (d) transferring the toner image to a substrate.

As described herein, an organophotoreceptor comprises a charge transport compound having the formula



where R₁ and R₂ are, independently, hydrogen, an alkyl group, an alkaryl group or an aryl group; X is an aromatic group; Y is an (N,N-disubstituted)arylamine, such as a p-(N,N-disubstituted)arylamine, a julolidine group or a carbazole group; Z is (CH₂)_m group where m is an integer between 0 and 30 where one or more of the methylene groups is optionally replaced by O, S, C=O, O=C-O, O=C-NR₃, sulfoxide, sulfate, phosphate, an aryl group, urethane, urea, NR₄ group, CHR₅ group, or CR₆R₇ group where R₃, R₄, R₅, R₆, and R₇ are, independently, H, hydroxyl, thiol, an amine group, an alkyl group, an alkaryl group, a heterocyclic group, or an aryl group, and E is a bond, O, S, C=O, NR₈, CR₉R₁₀ group, a heterocyclic group, or an aromatic group where R₈, R₉, and R₁₀ are, independently, H, an alkyl group, an alkaryl group, or an aryl group.

Substitution is liberally allowed on the chemical groups to affect various physical effects on the properties of the compounds, such as mobility, sensitivity, solubility, stability, and the like, as is known generally in the art. In the description of chemical substituents, there are certain practices common to the art that are reflected in the use of language. The term group indicates that the generically recited chemical entity (e.g., alkyl group, phenyl group, julolidine group, (N,N-disubstituted) arylamine group, etc.) may have any substituent thereon which is consistent with the bond structure of that group. For example, where the term 'alkyl group' is used, that term would not only include unsubstituted liner, branched and cyclic alkyls, such as methyl, ethyl, isopropyl, tert-butyl, cyclohexyl, dodecyl and the like, but also substituents such as hydroxyethyl,

cyanobutyl, 1,2,3-trichloropropane, and the like. However, as is consistent with such nomenclature, no substitution would be included within the term that would alter the fundamental bond structure of the underlying group. For example, where a phenyl group is recited, substitution such as 1-hydroxyphenyl, 2,4-fluorophenyl, orthocyanophenyl, 5 1,3,5-trimethoxyphenyl and the like would be acceptable within the terminology, while substitution of 1,1,2,2,3,3-hexamethylphenyl would not be acceptable as that substitution would require the ring bond structure of the phenyl group to be altered to a non-aromatic form because of the substitution. Similarly, when referring to carbazole group or julolidine group, the compound or substituent cited will include any substitution that does 10 not substantively alter the chemical nature of the carbazole ring or the julolidine ring in the formula. When referring to an (N,N-disubstituted)arylamine group, the two substituents attached to the nitrogen may be any group that will not substantively alter the chemical nature of the amine group. Where the term moiety is used, such as alkyl moiety or phenyl moiety, that terminology indicates that the chemical material is not substituted. 15 Where the term alkyl moiety is used, that term represents only an unsubstituted alkyl hydrocarbon group, whether branched, straight chain, or cyclic.

Organophotoreceptors

The organophotoreceptor may be, for example, in the form of a plate, a sheet, a 20 flexible belt, a disk, a rigid drum, or a sheet around a rigid or compliant drum, with flexible belts and rigid drums generally being used in commercial embodiments. The organophotoreceptor may comprise, for example, an electrically conductive substrate and on the electrically conductive substrate a photoconductive element in the form of one or more layers. The photoconductive element can comprise both a charge transport 25 compound and a charge generating compound in a polymeric binder, which may or may not be in the same layer, as well as an electron transport compound in some embodiments. For example, the charge transport compound and the charge generating compound can be in a single layer. In other embodiments, however, the photoconductive element comprises a bilayer construction featuring a charge generating layer and a separate charge transport layer. The charge generating layer may be located intermediate between the 30 electrically conductive substrate and the charge transport layer. Alternatively, the

photoconductive element may have a structure in which the charge transport layer is intermediate between the electrically conductive substrate and the charge generating layer.

The electrically conductive substrate may be flexible, for example in the form of a flexible web or a belt, or inflexible, for example in the form of a drum. A drum can have 5 a hollow cylindrical structure that provides for attachment of the drum to a drive that rotates the drum during the imaging process. Typically, a flexible electrically conductive substrate comprises an electrically insulating substrate and a thin layer of electrically conductive material onto which the photoconductive material is applied.

The electrically insulating substrate may be paper or a film forming polymer such 10 as polyester (e.g., polyethylene terephthalate or polyethylene naphthalate), polyimide, polysulfone, polypropylene, nylon, polyester, polycarbonate, polyvinyl resin, polyvinyl fluoride, polystyrene and the like. Specific examples of polymers for supporting substrates included, for example, polyethersulfone (StabarTM S-100, available from ICI), polyvinyl fluoride (Tedlar[®], available from E.I. DuPont de Nemours & Company), 15 polybisphenol-A polycarbonate (MakrofolTM, available from Mobay Chemical Company) and amorphous polyethylene terephthalate (MelinarTM, available from ICI Americas, Inc.). The electrically conductive materials may be graphite, dispersed carbon black, iodide, conductive polymers such as polypyroles and Calgon[®] conductive polymer 261 (commercially available from Calgon Corporation, Inc., Pittsburgh, Pa.), metals such as 20 aluminum, titanium, chromium, brass, gold, copper, palladium, nickel, or stainless steel, or metal oxide such as tin oxide or indium oxide. In embodiments of particular interest, the electrically conductive material is aluminum. Generally, the photoconductor substrate has a thickness adequate to provide the required mechanical stability. For example, flexible web substrates generally have a thickness from about 0.01 to about 1 25 mm, while drum substrates generally have a thickness of from about 0.5 mm to about 2 mm.

The charge generating compound is a material that is capable of absorbing light to generate charge carriers, such as a dye or pigment. Non-limiting examples of suitable charge generating compounds include, for example, metal-free phthalocyanines (e.g., 30 ELA 8034 metal-free phthalocyanine available from H.W. Sands, Inc. or Sanyo Color Works, Ltd., CGM-X01), metal phthalocyanines such as titanium phthalocyanine, copper

phthalocyanine, oxytitanium phthalocyanine (also referred to as titanyl oxyphthalocyanine, and including any crystalline phase or mixtures of crystalline phases that can act as a charge generating compound), hydroxygallium phthalocyanine, squarylium dyes and pigments, hydroxy-substituted squarylium pigments, perylimides, 5 polynuclear quinones available from Allied Chemical Corporation under the tradename Indofast® Double Scarlet, Indofast® Violet Lake B, Indofast® Brilliant Scarlet and Indofast® Orange, quinacridones available from DuPont under the tradename Monastral™ Red, Monastral™ Violet and Monastral™ Red Y, naphthalene 1,4,5,8-tetracarboxylic acid derived pigments including the perinones, tetrabenzoporphyrins and 10 tetranaphthaloporphyrins, indigo- and thioindigo dyes, benzothioxanthene-derivatives, perylene 3,4,9,10-tetracarboxylic acid derived pigments, polyazo-pigments including bisazo-, trisazo- and tetrakisazo-pigments, polymethine dyes, dyes containing quinazoline groups, tertiary amines, amorphous selenium, selenium alloys such as selenium-tellurium, 15 selenium-tellurium-arsenic and selenium-arsenic, cadmium sulphoselenide, cadmium selenide, cadmium sulphide, and mixtures thereof. For some embodiments, the charge generating compound comprises oxytitanium phthalocyanine (e.g., any phase thereof), hydroxygallium phthalocyanine or a combination thereof.

The photoconductive layer of this invention may contain an electron transport compound. Generally, any electron transport compound known in the art can be used. 20 Non-limiting examples of suitable electron transport compound include, for example, bromoaniline, tetracyanoethylene, tetracyanoquinodimethane, 2,4,7-trinitro-9-fluorenone, 2,4,5,7-tetranitro-9-fluorenone, 2,4,5,7-tetranitroxanthone, 2,4,8-trinitrothioxanthone, 2,6,8-trinitro-indeno4H-indeno[1,2-b]thiophene-4-one, and 1,3,7-trinitrobienzo thiophene-5,5-dioxide, (2,3-diphenyl-1-indenylidene)malononitrile, 4H-thiopyran-1,1- 25 dioxide and its derivatives such as 4-dicyanomethylene-2,6-diphenyl-4H-thiopyran-1,1-dioxide, 4-dicyanomethylene-2,6-di-m-tolyl-4H-thiopyran-1,1-dioxide, and unsymmetrically substituted 2,6-diaryl-4H-thiopyran-1,1-dioxide such as 4H-1,1-dioxo-2-(p-isopropylphenyl)-6-phenyl-4-(dicyanomethylidene)thiopyran and 4H-1,1-dioxo-2-(p-isopropylphenyl)-6-(2-thienyl)-4-(dicyanomethylidene)thiopyran, derivatives of 30 phospha-2,5-cyclohexadiene, alkoxycarbonyl-9-fluorenylidene)malononitrile derivatives such as (4-n-butoxycarbonyl-9-fluorenylidene)malononitrile, (4-phenethoxycarbonyl-9-

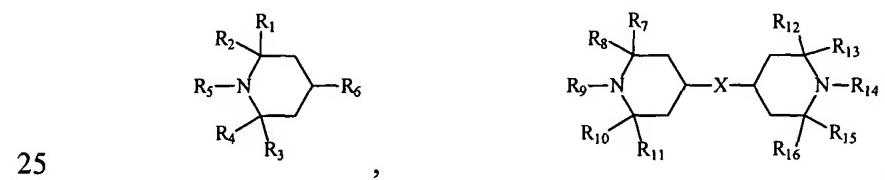
fluorenylidene)malononitrile, (4-carbitoxy-9-fluorenylidene)malononitrile, and diethyl(4-n-butoxycarbonyl-2,7-dinitro-9-fluorenylidene)-malonate, anthraquinodimethane derivatives such as 11,11,12,12-tetracyano-2-alkylanthraquinodimethane and 11,11-dicyano-12,12-bis(ethoxycarbonyl)anthraquinodimethane, anthrone derivatives such as 1-chloro-10-[bis(ethoxycarbonyl)methylene]anthrone, 1,8-dichloro-10-[bis(ethoxycarbonyl)methylene]anthrone, 1,8-dihydroxy-10-[bis(ethoxycarbonyl)methylene]anthrone, and 1-cyano-10-[bis(ethoxycarbonyl)methylene]anthrone, 7-nitro-2-aza-9-fluroenylidene-malononitrile, diphenoquinone derivatives, benzoquinone derivatives, naphtoquinone derivatives, quinine derivatives, tetracyanoethylenecyanoethylene, 2,4,8-trinitro thioxantone, dinitrobenzene derivatives, dinitroanthracene derivatives, dinitroacridine derivatives, nitroanthraquinone derivatives, dinitroanthraquinone derivatives, succinic anhydride, maleic anhydride, dibromo maleic anhydride, pyrene derivatives, carbazole derivatives, hydrazone derivatives, N,N-dialkylaniline derivatives, diphenylamine derivatives, triphenylamine derivatives, triphenylmethane derivatives, tetracyano quinoedimethane, 2,4,5,7-tetranitro-9-fluorenone, 2,4,7-trinitro-9-dicyanomethylene fluorenone, 2,4,5,7-tetranitroxanthone derivatives, and 2,4,8-trinitrothioxanthone derivatives. In some embodiments of interest, the electron transport compound comprises an (alkoxycarbonyl-9-fluorenylidene)malononitrile derivative, such as (4-n-butoxycarbonyl-9-fluorenylidene)malononitrile.

An electron transport compound and a UV light stabilizer can have a synergistic relationship for providing desired electron flow within the photoconductor. The presence of the UV light stabilizers alters the electron transport properties of the electron transport compounds to improve the electron transporting properties of the composite. UV light stabilizers can be ultraviolet light absorbers or ultraviolet light inhibitors that trap free radicals.

UV light absorbers can absorb ultraviolet radiation and dissipate it as heat. UV light inhibitors are thought to trap free radicals generated by the ultraviolet light and after trapping of the free radicals, subsequently to regenerate active stabilizer moieties with energy dissipation. In view of the synergistic relationship of the UV stabilizers with electron transport compounds, the particular advantages of the UV stabilizers may not be their UV stabilizing abilities, although the UV stabilizing ability may be further

advantageous in reducing degradation of the organophotoreceptor over time. While not wanting to be limited by theory, the synergistic relationship contributed by the UV stabilizers may be related to the electronic properties of the compounds, which contribute to the UV stabilizing function, by further contributing to the establishment of electron conduction pathways in combination with the electron transport compounds. In particular, the organophotoreceptors with a combination of the electron transport compound and the UV stabilizer can demonstrate a more stable acceptance voltage V_{acc} with cycling. The improved synergistic performance of organophotoreceptors with layers comprising both an electron transport compound and a UV stabilizer are described further in copending U.S. Patent Application Serial Number 10/425,333 filed on April 28, 2003 to Zhu, entitled "Organophotoreceptor With A Light Stabilizer," incorporated herein by reference.

Non-limiting examples of suitable light stabilizer include, for example, hindered trialkylamines such as Tinuvin 144 and Tinuvin 292 (from Ciba Specialty Chemicals, Terrytown, NY), hindered alkoxydialkylamines such as Tinuvin 123 (from Ciba Specialty Chemicals), benzotriazoles such as Tinuvan 328, Tinuvin 900 and Tinuvin 928 (from Ciba Specialty Chemicals), benzophenones such as Sanduvor 3041 (from Clariant Corp., Charlotte, N.C.), nickel compounds such as Arbestab (from Robinson Brothers Ltd, West Midlands, Great Britain), salicylates, cyanocinnamates, benzylidene malonates, benzoates, oxanilides such as Sanduvor VSU (from Clariant Corp., Charlotte, N.C.), triazines such as Cyagard UV-1164 (from Cytec Industries Inc., N.J.), polymeric sterically hindered amines such as Luchem (from Atochem North America, Buffalo, NY). In some embodiments, the light stabilizer is selected from the group consisting of hindered trialkylamines having the following formula:



where $R_1, R_2, R_3, R_4, R_6, R_7, R_8, R_{10}, R_{11}, R_{12}, R_{13}, R_{14}, R_{15}$ are, independently, hydrogen, alkyl group, or ester, or ether group; and R_5, R_9 , and R_{14} are, independently, alkyl group; and X is a linking group selected from the group consisting of $-O-CO-(CH_2)_m-CO-O-$ where m is between 2 to 20.

The binder generally is capable of dispersing or dissolving the charge transport compound (in the case of the charge transport layer or a single layer construction), the charge generating compound (in the case of the charge generating layer or a single layer construction) and/or an electron transport compound for appropriate embodiments.

- 5 Examples of suitable binders for both the charge generating layer and charge transport layer generally include, for example, polystyrene-co-butadiene, polystyrene-co-acrylonitrile, modified acrylic polymers, polyvinyl acetate, styrene-alkyd resins, soya-alkyl resins, polyvinylchloride, polyvinylidene chloride, polyacrylonitrile, polycarbonates, polyacrylic acid, polyacrylates, polymethacrylates, styrene polymers, polyvinyl butyral,
10 alkyd resins, polyamides, polyurethanes, polyesters, polysulfones, polyethers, polyketones, phenoxy resins, epoxy resins, silicone resins, polysiloxanes, poly(hydroxyether) resins, polyhydroxystyrene resins, novolak, poly(phenylglycidyl ether)-co-dicyclopentadiene, copolymers of monomers used in the above-mentioned polymers, and combinations thereof. Suitable binders include, for example, polyvinyl
15 butyral, such as BX-1 and BX-5 from Sekisui Chemical Co. Ltd., Japan.

Suitable optional additives for any one or more of the layers include, for example, antioxidants, coupling agents, dispersing agents, curing agents, surfactants and combinations thereof.

- The photoconductive element overall typically has a thickness from about 10 to
20 about 45 microns. In the dual layer embodiments having a separate charge generating layer and a separate charge transport layer, charge generation layer generally has a thickness from about 0.5 to about 2 microns, and the charge transport layer has a thickness from about 5 to about 35 microns. In embodiments in which the charge transport compound and the charge generating compound are in the same layer, the layer
25 with the charge generating compound and the charge transport composition generally has a thickness from about 7 to about 30 microns. In embodiments with a distinct electron transport layer, the electron transport layer has an average thickness from about 0.5 microns to about 10 microns and in further embodiments from about 1 micron to about 3 microns. In general, an electron transport overcoat layer can increase mechanical
30 abrasion resistance, increases resistance to carrier liquid and atmospheric moisture, and decreases degradation of the photoreceptor by corona gases. A person of ordinary skill in

the art will recognize that additional ranges of thickness within the explicit ranges above are contemplated and are within the present disclosure.

Generally, for the organophotoreceptors described herein, the charge generation compound is in an amount from about 0.5 to about 25 weight percent in further 5 embodiments in an amount from about 1 to about 15 weight percent and in other embodiments in an amount from about 2 to about 10 weight percent, based on the weight of the photoconductive layer. The charge transport compound is in an amount from about 10 to about 80 weight percent, based on the weight of the photoconductive layer, in further embodiments in an amount from about 35 to about 60 weight percent, and in other 10 embodiments from about 45 to about 55 weight percent, based on the weight of the photoconductive layer. The optional electron transport compound, when present, can be in an amount of at least about 2 weight percent, in other embodiments from about 2.5 to about 25 weight percent, based on the weight of the photoconductive layer, and in further 15 embodiments in an amount from about 4 to about 20 weight percent, based on the weight of the photoconductive layer. The binder is in an amount from about 15 to about 80 weight percent, based on the weight of the photoconductive layer, and in further embodiments in an amount from about 20 to about 75 weight percent, based on the weight of the photoconductive layer. A person of ordinary skill in the art will recognize that additional ranges within the explicit ranges of compositions are contemplated and are 20 within the present disclosure.

For the dual layer embodiments with a separate charge generating layer and a charge transport layer, the charge generation layer generally comprises a binder in an amount from about 10 to about 90 weight percent, in further embodiments from about 15 to about 80 weight percent and in some embodiments in an amount of from about 20 to 25 about 75 weight percent, based on the weight of the charge generation layer. The optional electron transport compound in the charge generating layer, if present, generally can be in an amount of at least about 2.5 weight percent, in further embodiments from about 4 to about 30 weight percent and in other embodiments in an amount from about 10 to about 25 weight percent, based on the weight of the charge generating layer. The 30 charge transport layer generally comprises a binder in an amount from about 20 weight percent to about 70 weight percent and in further embodiments in an amount from about

30 weight percent to about 50 weight percent. A person of ordinary skill in the art will recognize that additional ranges of binder concentrations for the dual layer embodiments within the explicit ranges above are contemplated and are within the present disclosure.

For the embodiments with a single layer having a charge generating compound and a charge transport compound, the photoconductive layer generally comprises a binder, a charge transport compound and a charge generation compound. The charge generation compound can be in an amount from about 0.05 to about 25 weight percent and in further embodiment in an amount from about 2 to about 15 weight percent, based on the weight of the photoconductive layer. The charge transport compound can be in an amount from

10 about 10 to about 80 weight percent, in other embodiments from about 25 to about 65 weight percent, in additional embodiments from about 30 to about 60 weight percent and in further embodiments in an amount of from about 35 to about 55 weight percent, based on the weight of the photoconductive layer, with the remainder of the photoconductive layer comprising the binder, and optionally additives, such as any conventional additives.

15 A single layer with a charge transport composition and a charge generating compound generally comprises a binder in an amount from about 10 weight percent to about 75 weight percent, in other embodiments from about 20 weight percent to about 60 weight percent, and in further embodiments from about 25 weight percent to about 50 weight percent. Optionally, the layer with the charge generating compound and the charge 20 transport compound may comprise an electron transport compound. The optional electron transport compound, if present, generally can be in an amount of at least about 2.5 weight percent, in further embodiments from about 4 to about 30 weight percent and in other embodiments in an amount from about 10 to about 25 weight percent, based on the weight of the photoconductive layer. A person of ordinary skill in the art will 25 recognize that additional composition ranges within the explicit compositions ranges for the layers above are contemplated and are within the present disclosure.

In general, any layer with an electron transport layer can advantageously further include a UV light stabilizer. In particular, the electron transport layer generally can comprise an electron transport compound, a binder and an optional UV light stabilizer. 30 An overcoat layer comprising an electron transport compound is described further in copending U.S. Patent Application Serial No. 10/396,536 to Zhu et al. entitled,

“Organophotoreceptor With An Electron Transport Layer,” incorporated herein by reference. For example, an electron transport compound as described above may be used in the release layer of the photoconductors described herein. The electron transport compound in an electron transport layer can be in an amount from about 10 to about 50 weight percent, and in other embodiments in an amount from about 20 to about 40 weight percent, based on the weight of the electron transport layer. A person of ordinary skill in the art will recognize that additional ranges of compositions within the explicit ranges are contemplated and are within the present disclosure.

The UV light stabilizer, if present, in any of one or more appropriate layers of the photoconductor generally is in an amount from about 0.5 to about 25 weight percent and in some embodiments in an amount from about 1 to about 10 weight percent, based on the weight of the particular layer. A person of ordinary skill in the art will recognize that additional ranges of compositions within the explicit ranges are contemplated and are within the present disclosure.

For example, the photoconductive layer may be formed by dispersing or dissolving the components, such as one or more of a charge generating compound, a charge transport compound, an electron transport compound, a UV light stabilizer, and a polymeric binder in organic solvent, coating the dispersion and/or solution on the respective underlying layer and drying the coating. In particular, the components can be dispersed by high shear homogenization, ball-milling, attritor milling, high energy bead (sand) milling or other size reduction processes or mixing means known in the art for effecting particle size reduction in forming a dispersion.

The photoreceptor may optionally have one or more additional layers as well. An additional layer can be, for example, a sub-layer or an overcoat layer, such as a barrier layer, a release layer, a protective layer, or an adhesive layer. A release layer or a protective layer may form the uppermost layer of the photoconductor element. A barrier layer may be sandwiched between the release layer and the photoconductive element or used to overcoat the photoconductive element. The barrier layer provides protection from abrasion to the underlayers. An adhesive layer locates and improves the adhesion between a photoconductive element, a barrier layer and a release layer, or any combination thereof. A sub-layer is a charge blocking layer and locates between the

electrically conductive substrate and the photoconductive element. The sub-layer may also improve the adhesion between the electrically conductive substrate and the photoconductive element.

Suitable barrier layers include, for example, coatings such as crosslinkable siloxanol-colloidal silica coating and hydroxylated silsesquioxane-colloidal silica coating, and organic binders such as polyvinyl alcohol, methyl vinyl ether/maleic anhydride copolymer, casein, polyvinyl pyrrolidone, polyacrylic acid, gelatin, starch, polyurethanes, polyimides, polyesters, polyamides, polyvinyl acetate, polyvinyl chloride, polyvinylidene chloride, polycarbonates, polyvinyl butyral, polyvinyl acetoacetal, polyvinyl formal, polyacrylonitrile, polymethyl methacrylate, polyacrylates, polyvinyl carbazoles, copolymers of monomers used in the above-mentioned polymers, vinyl chloride/vinyl acetate/vinyl alcohol terpolymers, vinyl chloride/vinyl acetate/maleic acid terpolymers, ethylene/vinyl acetate copolymers, vinyl chloride/vinylidene chloride copolymers, cellulose polymers, and mixtures thereof. The above barrier layer polymers optionally may contain small inorganic particles such as fumed silica, silica, titania, alumina, zirconia, or a combination thereof. Barrier layers are described further in U.S. Patent 6,001,522 to Woo et al., entitled "Barrier Layer For Photoconductor Elements Comprising An Organic Polymer And Silica," incorporated herein by reference. The release layer topcoat may comprise any release layer composition known in the art. In some embodiments, the release layer is a fluorinated polymer, siloxane polymer, fluorosilicone polymer, silane, polyethylene, polypropylene, polyacrylate, or a combination thereof. The release layers can comprise crosslinked polymers.

The release layer may comprise, for example, any release layer composition known in the art. In some embodiments, the release layer comprises a fluorinated polymer, siloxane polymer, fluorosilicone polymer, polysilane, polyethylene, polypropylene, polyacrylate, poly(methyl methacrylate-co-methacrylic acid), urethane resins, urethane-epoxy resins, acrylated-urethane resins, urethane-acrylic resins, or a combination thereof. In further embodiments, the release layers comprise crosslinked polymers.

The protective layer can protect the organophotoreceptor from chemical and mechanical degradation. The protective layer may comprise any protective layer

composition known in the art. In some embodiments, the protective layer is a fluorinated polymer, siloxane polymer, fluorosilicone polymer, polysilane, polyethylene, polypropylene, polyacrylate, poly(methyl methacrylate-co-methacrylic acid), urethane resins, urethane-epoxy resins, acrylated-urethane resins, urethane-acrylic resins, or a combination thereof. In some embodiments of particular interest, the release layers are crosslinked polymers.

An overcoat layer may comprise an electron transport compound as described further in copending U.S. Patent Application Serial No. 10/396,536, filed on March 25, 2003 to Zhu et al. entitled, "Organoreceptor With An Electron Transport Layer," incorporated herein by reference. For example, an electron transport compound, as described above, may be used in the release layer of this invention. The electron transport compound in the overcoat layer can be in an amount from about 2 to about 50 weight percent, and in other embodiments in an amount from about 10 to about 40 weight percent, based on the weight of the release layer. A person of ordinary skill in the art will recognize that additional ranges of composition within the explicit ranges are contemplated and are within the present disclosure.

Generally, adhesive layers comprise a film forming polymer, such as polyester, polyvinylbutyral, polyvinylpyrrolidone, polyurethane, polymethyl methacrylate, poly(hydroxy amino ether) and the like. Barrier and adhesive layers are described further in U.S. Patent 6,180,305 to Ackley et al., entitled "Organic Photoreceptors for Liquid Electrophotography," incorporated herein by reference.

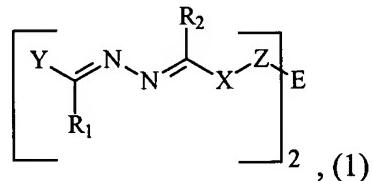
Sub-layers can comprise, for example, polyvinylbutyral, organosilanes, hydrolyzable silanes, epoxy resins, polyesters, polyamides, polyurethanes, silicones and the like. In some embodiments, the sub-layer has a dry thickness between about 20 Angstroms and about 2,000 Angstroms. Sublayers containing metal oxide conductive particles can be between about 1 and about 25 microns thick. A person of ordinary skill in the art will recognize that additional ranges of compositions and thickness within the explicit ranges are contemplated and are within the present disclosure.

The charge transport compounds as described herein, and photoreceptors including these compounds, are suitable for use in an imaging process with either dry or liquid toner development. For example, any dry toners and liquid toners known in the art

may be used in the process and the apparatus of this invention. Liquid toner development can be desirable because it offers the advantages of providing higher resolution images and requiring lower energy for image fixing compared to dry toners. Examples of suitable liquid toners are known in the art. Liquid toners generally comprise toner particles dispersed in a carrier liquid. The toner particles can comprise a colorant/pigment, a resin binder, and/or a charge director. In some embodiments of liquid toner, a resin to pigment ratio can be from 1:1 to 10:1, and in other embodiments, from 4:1 to 8:1. Liquid toners are described further in Published U.S. Patent Applications 2002/0128349, entitled "Liquid Inks Comprising A Stable Organosol," 10 2002/0086916, entitled "Liquid Inks Comprising Treated Colorant Particles," and 2002/0197552, entitled "Phase Change Developer For Liquid Electrophotography," all three of which are incorporated herein by reference.

Charge Transport Compound

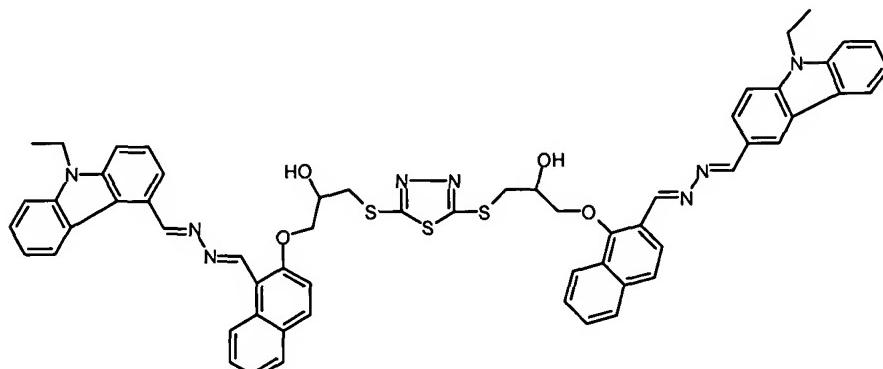
15 As described herein, an organophotoreceptor comprises a charge transport compound having the formula



where R₁ and R₂ are, independently, hydrogen, an alkyl group, an alkaryl group or an aryl group; X is an aromatic group; Y is an (N,N-disubstituted)arylamine; Z is (CH₂)_m group where m is an integer between 0 and 30 where one or more of the methylene groups is optionally replaced by O, S, C=O, O=C-O, O=C-NR₃, sulfoxide, sulfate, phosphate, an aryl group, urethane, urea, NR₄ group, CHR₅ group, or CR₆R₇ group where R₃, R₄, R₅, R₆, and R₇ are, independently, H, hydroxyl, thiol, an amine group, an alkyl group, an alkaryl group, a heterocyclic group, or an aryl group, and E is a bond, O, S, C=O, NR₈, CR₉R₁₀ group, a heterocyclic group, or an aromatic group where R₈, R₉, and R₁₀ are, independently, H, an alkyl group, an alkaryl group, or an aryl group. In some embodiments, Y can be a such as a julolidine group, a carbazole group or a p-(N,N-

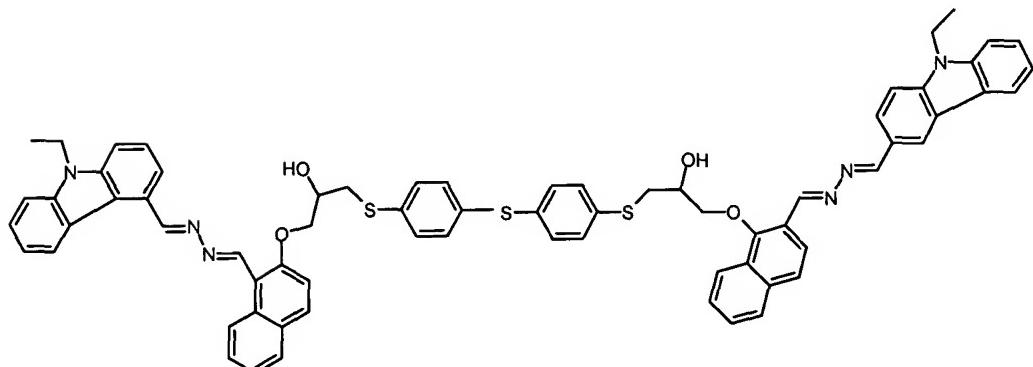
disubstituted)arylamine, such as triphenyl amine. Also, in some embodiments, X can be selected from the group consisting of phenylene group, naphthalene group, and (N,N-disubstituted) aminophenylene group. Furthermore, in some embodiments, E can be an aromatic group, such as a thiadiazole group or a thiobisbenzenethiol group.

5 Specific, non-limiting examples of suitable charge transport compounds within the general Formula (1) of the present invention have the following structures:

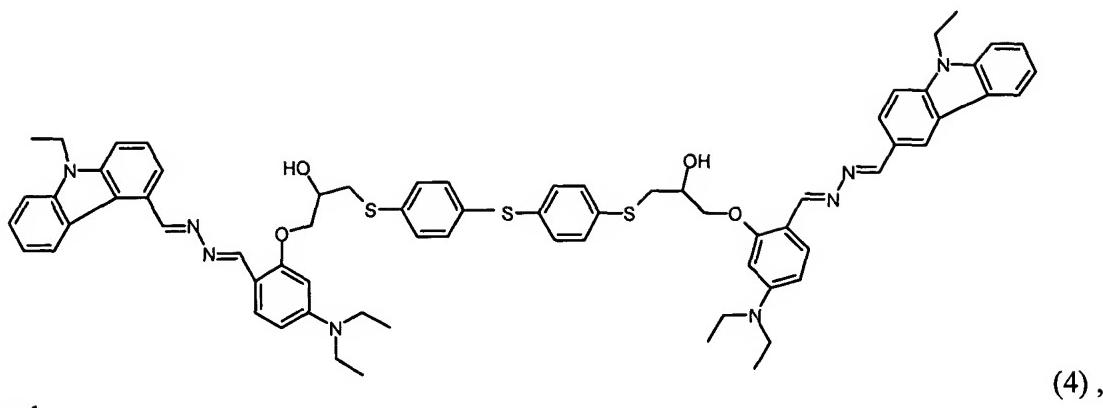


(2),

10

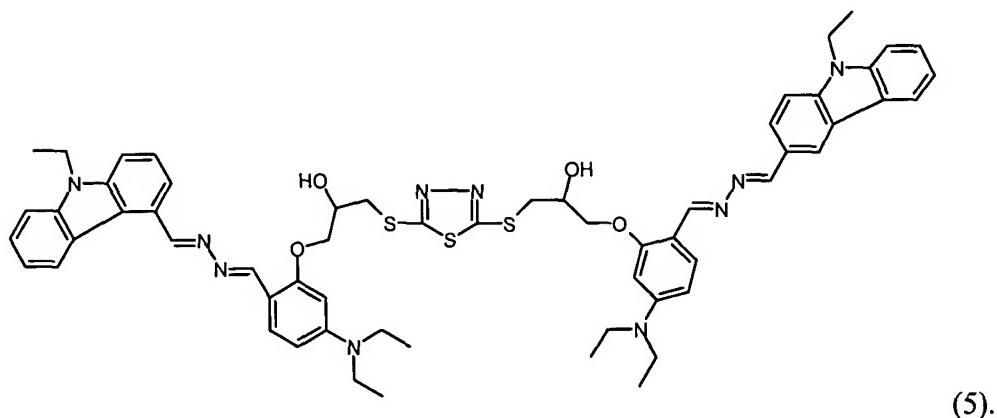


(3),



and

5



10 Synthesis of Charge Transport Compounds

The synthesis of the charge transport compounds can be based on the synthesis of the azine compounds that are then dimerized to form the charge transport compounds.

The synthesis of the azine compounds can be based on hydrazine monohydrate, which is available from Aldrich (Milwaukee, WI). Specifically, the azine compounds described

15 herein can be synthesized by reacting hydrazine monohydrate with two aromatic aldehydes/ketones. One of the aldehydes/ketones is an N,N-disubstituted amino aryl substituted aldehyde or ketone, which reacts with a hydrazine in an appropriate base catalyzed reaction to form a hydrazone. This aldehyde or ketone provides the Y group and the R₁ in Formula (1). The other substituted aldehyde/ketone is a functionalized
20 aromatic aldehyde or ketone, which similarly reacts with a hydrazine to form a hydrazone.

This functionalized aromatic aldehyde or ketone is functionalized to provide a functional group that can be reacted to form the -Z- group of the product charge transport compound along with an appropriate functional group to form the bridging E-group, as described further below. Also, this functionalized aromatic aldehyde or ketone provides the X group and the R₂ group of Formula (1). The two aldehydes/ketones can be reacted sequentially to first form a hydrazone that is subsequently reacted to form the azine.

In some embodiments, the bridging -Z-E-Z- group can be formed by reacting a difunctional compound with a structure -Z-E-Z- with a functional group of the X group to direct form the bridged charge transport compound of Formula (1). In other 10 embodiments, the Z group is first added to the azine compound with the form Z-F in which the F group is a functional group for reacting with the bridging E group. In some embodiments of particular interest, F is an epoxy, i. e. epoxide, group.

The azine that is formed can be reacted to form an epoxy derivatized compound. For example, the functionalized aromatic group can be functionalized with active 15 hydrogens, such as a primary amino group, a secondary amino group, a hydroxyl group, or a mercapto group. The functionalized compound reacts with the epichlorohydrin by way of the active hydrogen, such as in a base catalyzed reaction, to form the epoxy group with a -CH₂- group (as the Z-group) between the epoxy group and the aromatic X group. While epichlorohydrin can be used to form the epoxy substituted compound with Z = 20 -CH₂-, alternatively other Z groups can be formed, for example, using two functional groups, specifically, with a halogen and with a vinyl group (C=C) or substituted vinyl group. The halide group can be replaced by a bond to the group with the active hydrogen of the azine through a nucleophilic substitution. The vinyl or substituted vinyl group can be converted to the epoxy group in a epoxidation reaction, for example, by the reaction 25 with perbenzoic acid or other peroxy acid, in an electrophilic addition reaction. Thus, the identity of Z can be selected as desired through the introduction of a difunctional compound with a halide group and a vinyl/substituted- vinyl group.

The epoxy-derivatized azine compounds can then be reacted with a compound comprising the E group and two functional groups with an active hydrogen that can add 30 at the epoxy group. Thus, the azine dimer charge transport compounds can be formed.

Arylaldehydes

As noted above, two aryl aldehydes/ketones are reacted to form the charge transport compounds. One of the arylaldehydes or arylketones is a (N,N-disubstituted) arylamine aldehyde. Representative (N,N-disubstituted) arylamine aldehydes for reacting with the hydrazine can be obtained as follows. A wide range of aryl aldehydes can be used for the other aldehyde reactant, including a variety of commercially available compounds. Two representative commercially available arylaldehydes are described in the examples below.

Synthesis Of Julolidine Aldehyde

Julolidine (100 g, 0.6 moles, commercially obtained from Aldrich Chemicals Co, Milwaukee, WI 53201) was dissolved in N,N-dimethylformamide (DMF) (200 ml, commercially obtained from Aldrich) in a 500 ml three neck round bottom flask. The flask was cooled to 0 °C in ice bath. Phosphorus trichloride oxide (POCl₃) (107 g, 0.7 mole, Aldrich) was added drop wise while keeping the temperature below 5 °C. After the addition of POCl₃ was completed, the flask was warmed to room temperature and placed in a steam bath while stirring for a period of 1 hour. The flask was cooled to room temperature, and the solution was added slowly to a large excess of distilled water with good agitation. Stirring was continued for additional 2 hours. The solid was filtered off and washed repeatedly with water until the effluent water became neutral. The product was dried in vacuum oven at 50 °C for 4 hours.

Other Aryl Aldehydes

Suitable commercially available (N,N-disubstituted)arylamine aldehydes are available form Aldrich (Milwaukee, WI) including, for example, diphenylamino-benzaldehyde ((C₆H₅)₂NC₆H₄CHO) and 9-ethyl-3-carbazolecarboxyaldehyde.

Synthesis of Hydrazones

A hydrazine can be reacted with an appropriate aromatic aldehyde/ketone to form a desired hydrazone. The reactions can be catalyzed by an appropriate amount of a basic compound, in particular triethyl amine. After mixing in the catalytic amount of base with the hydrazine and aromatic aldehyde, the mixture can be refluxed for about 2 hours to

about 16 hours. The initial product can be purified by recrystallization. The syntheses of selected compounds from the formulas above are described below in the Examples, and the other compounds described herein can be similarly synthesized.

5 The invention will now be described further by way of the following examples.

EXAMPLES

Example 1 - Synthesis of Charge Transport Compounds

This example describes the synthesis of four charge transport compounds
10 corresponding to formulas 2-5 above.

Compound (2)

A quantity of 98% by weight hydrazine monohydrate (50 ml, 1.4 mole, obtained from Aldrich, Milwaukee, WI) and 10 ml of triethylamine (obtained from Aldrich, Milwaukee, WI) were added to a 250 ml, 2-neck round bottom flask equipped with a
15 mechanical stirrer and an addition funnel. The solution was stirred vigorously at room temperature for a period of 10-15 min. Then, a solution of 9-ethyl-3-carbazolecarboxaldehyde (22.3 g, 0.1 mol, obtained from Aldrich, Milwaukee, WI) in 30 ml of tetrahydrofuran (THF) was added slowly to the round bottom flask. After the addition of aldehyde was completed, the reaction mixture was stirred at room temperature
20 for 2 hours. The mixture was diluted with 50 ml of water. A precipitate was collected by filtration and washed repeatedly with water to give the crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone, which was used in the next step immediately.

The crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone (23.7 g, 0.1 mole, obtained in the previous step) was added to a refluxed solution of 2-hydroxy-1-naphthaldehyde (17.2 g, 0.1 mol, obtained from Aldrich, Milwaukee, WI) in 50 ml of dioxane. The reflux process was continued for 10-15 min, and then the reaction mixture was allowed to stand at room temperature. Crystals that formed upon standing were filtered off and washed with 2-propanol and ether to give 38 g (for a 97 % yield) of the expected azine. The azine product was recrystallized from dioxane to yield a product
25 with a melting point of 184-186 °C (from dioxane). The ¹H-NMR spectrum (100 MHz, CDCl₃) showed the following chemical shifts (ppm) : δ = 13.5 (s, 1H, OH); δ = 9.7 (s,

1H, one of CH=N); δ = 8.8 (s, 1H, one of CH=N); δ = 8.5 (s, 1H, 4-H Ht); δ = 8.3-7.1 (m, 12H, Ar); δ = 4.3 (q, J =7.1 Hz, 2H, NCH₂CH₃);); δ = 1.4 (t, 3H, J =7.1 Hz, NCH₂CH₃). An elemental analysis yielded in weight %: C =79.59; H= 5.38; N= 10.52, which compared with calculated values for C₂₆H₂₁N₃O in weight % of: C= 79.77; H= 5.41; N= 10.73.

The azine product (27.4 g, 0.07 mol, prepared in previous step) and epichlorohydrin (80 ml, 1 mol ,obtained from Aldrich, Milwaukee, WI) were added to a 250 ml 3-neck round bottom flask equipped with a reflux condenser, a thermometer and a mechanical stirrer. The reaction mixture was stirred vigorously at 35-40 °C for 24 h.

10 During the reaction period, powdered 85 % potassium hydroxide (26.8 g, 0.4 mol) and anhydrous sodium sulphate (6.8 g, 0.05 mol) were added in six portions by temporarily cooling the reaction mixture to 20-25 °C prior to the addition of these compounds. After the completion of the reaction, the mixture was cooled to room temperature and filtered.

15 The organic phase was treated with ethyl acetate and washed with distilled water until the wash water was neutral. The organic layer was dried over anhydrous magnesium sulfate, treated with activated charcoal, and filtered. Then, the solvent was removed. The residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich, Milwaukee, WI) using 1:4 by volume acetone/hexane as the eluant. Fractions containing the product were collected and evaporated to afford an oily residue that was

20 dissolved in a 30 ml blend of methanol/toluene, 1:1 by volume. The crystals that formed upon standing were filtered off and washed with 2-propanol to give 18 g (for a yield of 57 %) of epoxy-derivatized azine. The product had a melting point of 164.5-165.5 °C (from methanol/toluene, 1:1 by volume). The ¹H-NMR spectrum (100 MHz, CDCl₃) showed the following chemical shifts (ppm): δ = 9.5 (m, 1H, one of CH=N); δ = 9.0 (s,

25 1H, one of CH=N); δ = 8.6 (s, 1H, 4-HHt); δ = 8.3-7.2 (m, 12H, Ar); δ = 4.6-4.0 (m, 4H, OCH₂, NCH₂CH₃); δ = 3.45 (m, 1H, CH); 2.9 (dd, 1H, one of CH₂ of oxirane); δ = 2.7 (dd, 1H, one of CH₂ of oxirane); δ = 1.4 (t, 3H, CH₃). Elemental analysis yielded the following values in weight %: C =77.62; H=5.31; N= 9.17, which compared with calculated values for C₂₉H₂₅N₃O₂ in weight % of C=77.83; H= 5.63; N= 9.39.

30 Compound (2) was obtained from the epoxy-derivatized azine (5.1 g, 11.75 mmol, prepared in previous step) and 2,5-dimercapto-1,3,4-thiadiazol (0.86 g, 5.73 mmol,

obtained from Aldrich, Milwaukee, WI), which were reacted in the presence of triethylamine (TEA, 0.65 ml, 4.7 mmol, obtained from Aldrich, Milwaukee, WI) and isolated similar to the isolation procedure for Compound (3), described below. The yield of Compound (2) was 4.4 g (73 %). The ¹H-NMR spectrum (100 MHz, CDCl₃) showed
5 the following chemical shifts (ppm): δ = 9.5 (s, 2H, one of CH=N); δ = 8.9 (m, 4H, one of CH=N, Ar); δ = 8.5 (s, 2H, 4-H Ht); δ = 8.3-6.9 (m, 22H, Ar); δ = 4.5-3.8 (m, 12H, OCH₂CH(OH), NCH₂CH₃); δ = 3.5 (m, 4H, CH₂S); δ = 1.4 (t, 3H, NCH₂CH₃). Elemental analysis yielded the following values in weight %: C=68.84; H=4.91; N=10.60,
10 which compared with calculated values for C₆₀H₅₂N₈S₃O₄ in weight % of: C = 68.94; H = 5.01; N=10.72.

Compound (3)

A quantity of 98% hydrazine monohydrate (50 ml, 1.4 mole, obtained from Aldrich, Milwaukee , WI) and 10 ml of triethylamine (obtained from Aldrich, Milwaukee, WI) were added to a 250 ml, 2-neck round bottom flask equipped with a mechanical stirrer and an addition funnel. The solution was stirred vigorously at room temperature for a period of 10-15 min. A solution of 9-ethyl-3-carbazolecarboxaldehyde (22.3 g, 0.1 mol, obtained from Aldrich, Milwaukee, WI) in 30 ml of tetrahydrofuran (THF) was added slowly to the round bottom flask. After the addition of aldehyde was completed,
15 the reaction mixture was stirred at room temperature for 2 hours. Then, the mixture was diluted with 50 ml of water. A precipitate was collected by filtration and washed repeatedly with water to give the crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone, which was used in the next step immediately.

The crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone (23.7 g, 0.1 mole,
25 obtained in the previous step) was added to a refluxed solution of 2-hydroxy-1-naphthaldehyde (17.2 g, 0.1 mol, obtained from Aldrich, Milwaukee, WI) in 50 ml of dioxane. The reflux process was continued for 10-15 min, and then the reaction mixture was allowed to stand at room temperature. The crystals formed upon standing were filtered off and washed with 2-propanol and ether to give 38 g (for a yield of 97 %) of the
30 expected azine. The azine product was recrystallized from dioxane to yield a product with a melting point of 184-186 °C (from dioxane). The ¹H-NMR spectrum (100 MHz,

CDCl₃) showed the following chemical shifts (ppm): δ = 13.5 (s, 1H, OH); δ = 9.7 (s, 1H, one of CH=N); δ = 8.8 (s, 1H, one of CH=N); δ = 8.5 (s, 1H, 4-H Ht); δ = 8.3-7.1 (m, 12H, Ar); δ = 4.3 (q, J=7.1 Hz, 2H, NCH₂CH₃); δ = 1.4 (t, 3H, J=7.1 Hz, NCH₂CH₃). Elemental analysis yielded the following values in weight %: C = 79.59; H = 5.38; N = 5 10.52, which compared with calculated values for C₂₆H₂₁N₃O in weight percent of: C = 79.77; H = 5.41; N = 10.73.

The azine product (27.4 g, 0.07 mol, prepared in previous step) and epichlorohydrin (80 ml, 1 mol, obtained from Aldrich, Milwaukee, WI) were added to a 250 ml, 3-neck round bottom flask equipped with a reflux condenser, a thermometer and a mechanical stirrer. The reaction mixture was stirred vigorously at 35-40 °C for 24 h. During the reaction period, powdered 85 % potassium hydroxide (26.8 g, 0.4 mol) and anhydrous sodium sulphate (6.8 g, 0.05 mol) were added in six portions by temporarily cooling the reaction mixture to 20-25 °C prior to the addition of these compounds. After the completion of the reaction, the mixture was cooled to room temperature and filtered. 15 The organic phase was treated with ethyl acetate and washed with distilled water until the wash water was neutral. The organic layer was dried over anhydrous magnesium sulfate, treated with activated charcoal, and filtered. Then, the solvent was removed. The residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich, Milwaukee, WI) using 1:4 by volume acetone/hexane mixture as the eluant. 20 Fractions containing the product were collected and evaporated to afford an oily residue that was dissolved in the 30 ml of methanol/toluene, 1:1 by volume mixture. The crystals formed upon standing were filtered off and washed with 2-propanol to give 18 g (for a yield of 57 %) of the epoxy-derivatized azine. The product compound had a melting point of 164.5-165.5 °C (from methanol/toluene, 1/1). The ¹H-NMR spectrum (100 MHz, CDCl₃) showed the following chemical shifts (ppm): δ = 9.5 (m, 1H, one of CH=N); δ = 25 9.0 (s, 1H, one of CH=N); δ = 8.6 (s, 1H, 4-HHt); δ = 8.3-7.2 (m, 12H, Ar); δ = 4.6-4.0 (m, 4H, OCH₂, NCH₂CH₃); δ = 3.45 (m, 1H, CH); 2.9 (dd, 1H, one of CH₂ of oxirane); δ = 2.7 (dd, 1H, one of CH₂ of oxirane); δ = 1.4 (t, 3H, CH₃). Elemental analysis yielded the following values in weight %: C = 77.62; H = 5.31; N = 9.17, which compared with 30 calculated values for C₂₉H₂₅N₃O₂ in weight percent of: C = 77.83; H = 5.63; N = 9.39.

Triethylamine (TEA) (0.65 ml, 4.7 mmol, obtained from Aldrich, Milwaukee, WI) was added slowly to a solution of epoxy azine (5.1 g, 11.75 mmol, prepared in previous step) and 4,4'-thiobisbenzenethiol (1.44 g, 5.73 mmol, obtained from Aldrich, Milwaukee, WI) in 10 ml of 2-butanone, while the temperature of the reaction mixture
5 was maintained below 30 °C. The reaction mixture was stored over night at room temperature. After evaporation of the solvent, the residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich) using 1:4 by volume acetone/hexane mixture as the eluant. Fractions containing Compound (3) were collected, and the solvents were evaporated. A 20% by weight solution of the oily residue in
10 toluene was poured with intensive stirring into a tenfold excess of *n*-hexane to afford 4.6 g (for a 70 % yield) of Compound (3) as a precipitate. The ¹H-NMR spectrum (100 MHz, CDCl₃), showed the following chemical shifts (ppm): δ = 9.5 (s, 2H, one of CH=N); δ = 8.9 (s, 2H, one of CH=N); δ = 8.8 (d, 2H, Ar); δ = 8.6 (s, 2H, 4-HHt); δ = 8.3-6.9 (m, 32H, Ar); δ = 4.5-4.0 (m, 12H, OCH₂CH(OH), NCH₂CH₃); δ = 3.2 (d, 4H, CH₂S); δ =
15 1.4 (t,3H, J=7.1 Hz, NCH₂CH₃). Elemental analysis yielded the following values in weight %: C= 73.26; H= 5.09; N=7.17, which compared with calculated values for C₇₀H₆₀N₆S₃O₄ in weight percent of: C = 73.40; H =5.28; N =7.34.

Compound (4)

20 A quantity of 98% hydrazine monohydrate (50 ml, 1.4 mole, obtained from Aldrich, Milwaukee , WI) and 10 ml of triethylamine (obtained from Aldrich, Milwaukee, WI) were added to a 250 ml, 2-neck round bottom flask equipped with a mechanical stirrer and an addition funnel. The solution was stirred vigorously at room temperature for 10-15 min. A solution of 9-ethyl-3-carbazolecarboxaldehyde (22.3 g, 0.1 mol,
25 obtained from Aldrich, Milwaukee, WI) in 30 ml of tetrahydrofuran (THF) was slowly added. After the addition of aldehyde was completed, the reaction mixture was stirred at room temperature for 2 hours. Then, the mixture was diluted with 50 ml of water. A precipitate was collected by filtration and washed repeatedly with water to give the crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone, which was used in the next step
30 immediately.

The crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone (23.7 g, 0.1 mole, obtained in the previous step) were added to a refluxed solution of 4-diethylamino-2-hydroxybenzaldehyde (19.3 g, 0.1 mol, obtained from Aldrich, Milwaukee, WI) in 50 ml of dioxane. The reflux process was continued for 10-15 min, and then the dioxane was 5 evaporated. The residue was dissolved in a solution of toluene (20 ml) and 2-propanol (20 ml), and the mixture was allowed to stand at room temperature overnight. The crystals that formed upon standing were filtered off and washed with 2-propanol and ether to give 35 g (for a yield of 85 %) of azine with a melting point of 177-179 °C (from toluene). The ¹H-NMR spectrum (100MHz, CDCl₃) showed the following chemical 10 shifts (ppm): δ = 12.2 (s, 1H, OH); δ = 8.8 (s, 1H, CH=N); δ = 8.7 (s, 1H, CH=N); δ = 8.6 (s, 1H, 4-H Ht); δ = 8.4-7.9 (dd, 2H, 1-H, 2-H of Ht); δ = 7.6-7.1 (m, 5H, Ar); δ = 6.3 (m, 2H, 3-H, 5-H of 1,2,4-subst. Ph); δ = 4.4 (q, 2H, NCH₂CH₃); δ = 3.5 (q, 4H, N(CH₂CH₃)₂); δ = 1.5 (t, 3H, NCH₂CH₃); δ = 1.4 (t, 6H, N(CH₂CH₃)₂). Elemental 15 analysis yielded the following values in weight %: C= 75.59; H= 6.68; N= 13.52, which compared with calculated values for C₂₆H₂₈N₄O in weight percent of: C= 75.70; H= 6.84; N=13.58.

The azine product (28.9 g, 0.07 mol, prepared in previous step) and epichlorohydrin (80 ml, 1 mol, commercially available from Aldrich, Milwaukee, WI) were added to a 250 ml 3-neck round bottom flask equipped with a reflux condenser, a 20 thermometer and a mechanical stirrer. The reaction mixture was stirred vigorously at 35-40 °C for 24 h. During the reaction period, powdered 85 % potassium hydroxide (13.4 g, 0.2 mol) and anhydrous sodium sulphate (3.4 g, 25 mmol) were added in three portions by temporarily cooling the reaction mixture to 20-25 °C prior to the addition of these compounds. After completion of the reaction, the mixture was cooled to room 25 temperature and filtered. The organic phase was treated with ethyl acetate and washed with distilled water until the wash water was neutral. The organic layer was dried over anhydrous magnesium sulfate, treated with activated charcoal, filtered. Then, the solvent was evaporated. The residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich) using 1:4 by volume acetone/hexane mixture as the 30 eluant. Fractions containing the product were collected and evaporated to afford solid residue that was recrystallized from toluene/ethyl acetate (1:5 by volume mixture) to give

20 g (for a yield of 61 %) of epoxy-derivatized azine. The product had a melting point of 150-152 °C (from toluene/ethyl acetate, 1:5 by volume mixture). The ¹H-NMR spectrum (100 MHz, CDCl₃) showed the following chemical shifts (ppm): δ = 9.1 (s, 1H, one of CH=N); δ = 8.8 (s, 1H, one of CH=N); δ = 8.5 (s, 1H, 4-H Ht); δ = 8.4-7.9 (m, 3H, 6-H of 5 1,2,4-subst. Ph, 1-H, 2-H of Ht); δ = 7.65-7.2 (m, 4H, Ht); δ = 6.4 (d, 1H, 5-H of 1,2,4- subst. Ph); δ = 6.1 (s, 1H, 3-H of 1,2,4-subst. Ph); δ = 4.6-4.0 (m, 4H, OCH₂, NCH₂CH₃); δ = 3.6-3.2 (m, 5H, N(CH₂CH₃)₂, CH); δ = 2.9 (dd, 1H, one of CH₂ of oxirane); δ = 2.8 (dd, 1H, one of CH₂ of oxirane); δ = 1.5 (t, 3H, CH₂CH₃); δ = 1.5 (t, 6H, N(CH₂CH₃)₂). Elemental analysis yielded the following values in weight percent %: C= 74.32; H= 6.61; 10 N= 11.87, which compared with calculated values for C₂₆H₂₈N₄O in weight percent of: C= 74.33; H= 6.88; N=11.96.

TEA (0.65 ml, 4.7 mmol, obtained from Aldrich, Milwaukee, WI) was slowly added to the solution of epoxy azine (5.5 g, 11.75mmol, prepared in previous step) and 4,4'-thiobisbenzenethiol(1.44 g, 5.73 mmol, obtained from Aldrich , Milwaukee, WI) in 15 10 ml of 2-butanone, while the temperature of the reaction mixture was maintained below 30 °C. After addition of the TEA, the reaction mixture was stored overnight at room temperature. After evaporation of the solvent, the residue was subjected to column chromatography (silica gel, grade 62, 60-200 mesh, 150 Å, Aldrich) using 1:4 by volume acetone/hexane mixture as the eluant. Fractions containing Compound (4) were collected, 20 and the solvents were evaporated. A 20% solution of the oily residue in toluene was poured with intensive stirring into a ten fold excess of *n*-hexane to afford 4.9 g (for a yield of 72 %) of Compound (4) as a precipitate. The ¹H-NMR spectrum (100 MHz, CDCl₃) showed the following chemical shifts (ppm): δ = 8.82(s, 2H, one of CH=N); δ = 8.80 (s, 2H, one of CH=N); δ = 8.5 (s, 2H, 4-H of Ht); δ = 8.3-7.9 (dd, 4H, 1-H, 2-H of 25 Ht); δ = 7.8-7.0 (m, 10H, 6-H of 1,2,4-subst. Ph and 5-H, 6-H, 7-H, 8-H of Ht); δ = 6.5- 6.25 (d, 2H, 5-Hof 1,2,4-subst. Ph); δ = 6.1 (s, 2H, 3-H of 1,2,4-subst. Ph); δ = 4.6-4.05 (m, 10H, OCH₂CH, NCH₂CH₃); δ = 3.5-3.1 (m, 14H, SCH₂, OH, N(CH₂CH₃)₂); δ = 1.4 (t, 6H, NCH₂CH₃); δ = 1.2 (t, 12H, N(CH₂CH₃)₂). Elemental analysis yielded the following values in weight %: C=70.56; H=6.09; N= 9.27, which compared with 30 calculated values for C₇₀H₇₄N₈S₃O₄ in weight percent of: C=70.80; H=6.28; N=9.44.

Compound (5)

A quantity of 98% hydrazine monohydrate (50 ml, 1.4 mole, obtained from Aldrich, Milwaukee, WI) and 10 ml of triethylamine (obtained from Aldrich, Milwaukee, WI) were added to a 250 ml, 2-neck round bottom flask equipped with a mechanical stirrer and an addition funnel. The solution was stirred vigorously at room temperature for 10-15 min. A solution of 9-ethyl-3-carbazolecarboxaldehyde (22.3 g, 0.1 mol, obtained from Aldrich, Milwaukee, WI) in 30 ml of THF was slowly added to the round bottom flask. After the addition of aldehyde was completed, the reaction mixture was stirred at room temperature for 2 hours. Then, the mixture was diluted with 50 ml of water. The precipitate was collected by filtration and washed repeatedly with water to give the crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone, which was used in the next step immediately.

The crude 9-ethyl-3-carbazolecarboxaldehyde hydrazone (23.7 g, 0.1 mole, obtained in the previous step) was added to a refluxed solution of 4-diethylamino-2-hydroxybenzaldehyde (19.3 g, 0.1 mol, obtained from Aldrich, Milwaukee, WI) in 50 ml of dioxane. The reflux process was continued for 10-15 min, and then the dioxane was evaporated. The residue was dissolved in a solution of toluene (20 ml) and 2-propanol (20 ml), and the mixture was allowed to stand at room temperature overnight. The crystals that formed upon standing were filtered off and washed with 2-propanol and ether to give 35 g (for a yield of 85 %) of azine. The azine product had a melting point of 177-179 °C (from toluene). The ¹H-NMR spectrum (100MHz, CDCl₃) showed the following chemical shifts (ppm): δ = 12.2 (s, 1H, OH); δ = 8.8 (s, 1H, CH=N); δ = 8.7 (s, 1H, CH=N); δ = 8.6 (s, 1H, 4-H Ht); δ = 8.4-7.9 (dd, 2H, 1-H, 2-H of Ht); δ = 7.6-7.1 (m, 5H, Ar); δ = 6.3 (m, 2H, 3-H, 5-H of 1,2,4-subst. Ph); δ = 4.4 (q, 2H, NCH₂CH₃); δ = 3.5 (q, 4H, N(CH₂CH₃)₂); δ = 1.5 (t, 3H, NCH₂CH₃); δ = 1.4 (t, 6H, N(CH₂CH₃)₂). Elemental analysis yielded the following values in weight %: C= 75.59; H= 6.68; N= 13.52 , which compared with calculated values for C₂₆H₂₈N₄O in weight percent of: C= 75.70; H= 6.84; N =13.58.

The azine product (28.9 g, 0.07 mol, prepared in previous step) and epichlorohydrin (80 ml, 1 mol, commercially available from Aldrich, Milwaukee, WI) were added to a 250 ml 3-neck round bottom flask equipped with a reflux condenser, a

thermometer and a mechanical stirrer. The reaction mixture was stirred vigorously at 35-40 °C for 24 h. During the reaction period, powdered 85 % potassium hydroxide (13.4 g , 0.2 mol) and anhydrous sodium sulphate (3.4 g, 25 mmol) were added in three portions by temporarily cooling the reaction mixture to 20-25 °C prior to the addition of these 5 compounds. After termination of the reaction, the mixture was cooled to room temperature and filtered. The organic phase was treated with ethyl acetate and washed with distilled water until the wash water was neutral. The organic layer was dried over anhydrous magnesium sulfate, treated with activated charcoal, filtered. Then, the solvent was evaporated. The residue was subjected to column chromatography (silica gel, grade 10 62, 60-200 mesh, 150 Å, Aldrich) using 1:4 by volume mixture of acetone/hexane as the eluant. Fractions containing the product were collected and evaporated to afford a solid residue that was recrystallized from toluene/ethyl acetate (1:5 by volume mixture) to give 20 g (for a yield of 61 %) of epoxy-derivatized azine. The product had a melting point of 150-152 °C (from toluene/ethyl acetate, 1:5 by volume mixture). The ¹H-NMR spectrum 15 (100 MHz, CDCl₃) showed the following chemical shifts (ppm): δ = 9.1 (s, 1H, one of CH=N); δ = 8.8 (s, 1H, one of CH=N); δ = 8.5(s, 1H, 4-H Ht); δ = 8.4-7.9 (m, 3H, 6-H of 1,2,4-subst. Ph, 1-H, 2-H of Ht); δ = 7.65-7.2 (m, 4H, Ht); δ = 6.4(d, 1H, 5-H of 1,2,4- subst. Ph); δ = 6.1 (s, 1H, 3-H of 1,2,4-subst. Ph); δ = 4.6-4.0 (m, 4H, OCH₂, NCH₂CH₃); δ = 3.6-3.2 (m, 5H, N(CH₂CH₃)₂, CH); δ = 2.9 (dd, 1H, one of CH₂ of oxirane); δ = 2.8 (dd, 1H, one of CH₂ of oxirane); δ = 1.5(t, 3H, CH₂CH₃); δ = 1.5 (t, 6H, N(CH₂CH₃)₂). Elemental analysis yielded the following values in weight %: C= 74.32; H= 6.61; N= 20 11.87, which compared with calculated values for C₂₆H₂₈N₄O in weight percent of: C= 74.33; H= 6.88; N =11.96.

Compound (5) was obtained from the epoxy azine (5.5 g, 11.75 mmol, prepared 25 in previous step) and 2,5-dimercapto-1,3,4-thiadiazol (0.86 g, 5.73 mmol, obtained from Aldrich, Milwaukee , WI) in the presence of TEA (0.65 ml, 4.7 mmol, obtained from Aldrich , Milwaukee, WI) and was isolated similar to the procedure of Compound (4) above. The yield of Compound (5) was 4.9 g (79 %). The ¹H-NMRspectrum (100 MHz, CDCl₃) showed the following chemical shifts (ppm): δ = 8.8 (s, 4H, CH=N); 8.5 (s, 2H, 4-H of Ht); δ = 8.3-7.9 (dd, 4H, 1-H, 2-H of Ht); δ = 7.8-7.1 (m, 10H, 6-H of 1,2,4-subst. Ph and 5-H,6-H, 7-H, 8-H of Ht); δ = 6.5-6.25 (d, 2H, 5-H of 1,2,4-subst. Ph); δ = 6.1 (s,

2H, 3-H of 1,2,4-subst. Ph); δ = 4.6-4.0 (m, 10H, OCH₂CH, NCH₂CH₃); δ = 3.8-3.2 (m, 14H, SCH₂, OH, N(CH₂CH₃)₂); δ = 1.4 (t, 6H, NCH₂CH₃); δ = 1.2 (t, 12H, N(CH₂CH₃)₂). Elemental analysis yielded the following values in weight %: C=66.04; H=5.96; N=12.64, which compared with values for C₆₀H₆₆N₁₀S₃O₄ in weight percent of: C=66.27; H=6.12; 5 N=12.88.

Example 3 - Charge Mobility Measurements

This example describes the measurement of charge mobility for samples formed with the four charge transport compounds described in Example 2.

10 Sample 1

A mixture of 0.1 g of Compound 2 and 0.1 g of polycarbonate Z was dissolved in 2 ml of THF. The solution was coated on a polyester film with conductive aluminum layer by the dip roller method. After drying for 15 min. at 80°C temperature, a clear 10 μ m thick layer was formed. The photo discharge curve was too dispersive to give a clear 15 indication of the transit time for determination of mobility.

Sample 2

Sample 2 was prepared according to the procedure for Sample 1, except that Compound 3 was used in place of Compound 2.

Sample 3

20 Sample 3 was prepared according to the procedure for Sample 1, except that Compound 4 was used in place of Compound 2.

Sample 4

Sample 4 was prepared according to the procedure for Sample 1, except that Compound 5 was used in place of Compound 2.

25 Mobility Measurements

Each sample was corona charged positively up to a surface potential U, illuminated with 2 ns long nitrogen laser light pulse and the hole mobility μ was

determined as described in Kalade et al., "Investigation of charge carrier transfer in electrophotographic layers of chalkogenide glasses," Proceeding IPCS 1994: The Physics and Chemistry of Imaging Systems, Rochester, NY, pp. 747-752, incorporated herein by reference. This hole mobility measurement was repeated changing the charging regime 5 and charging the sample to different U values, which corresponded to different electric field strength inside the layer E. This dependence was approximated by the formula

$$\mu = \mu_0 e^{\alpha\sqrt{E}}$$

Here E is electric field strength, μ_0 is the zero field mobility and α is Pool-Frenkel parameter. The mobility characterizing parameters μ_0 and α values as well as the 10 mobility value at the 6.4×10^5 V/cm field strength as determined from these measurements are given in Table 1.

Table 1

Sample	μ_0 (cm ² /V·s)	μ (cm ² /V·s) at 6.4×10^5 V/cm	α (cm/V) ^{1/2}
1	~		
2	3.0×10^{-14}	1.50×10^{-10}	0.01
3	$\sim 1.0 \times 10^{-12}$	4.0×10^{-9}	0.01
4	4.0×10^{-12}	1.3×10^{-8}	~0.01

(Sample 1 hole mobility values could not be uniquely identified and measured due to dispersive hole transport of the material.)

15

Example 4 - Ionization Potential Measurements

This example describes the measurement of the ionization potential for the four charge transport compounds described in Example 2.

To perform the ionization potential measurements, a thin layer of charge transport 20 compound about 0.5 µm thickness was coated from a solution of 2 mg of charge transport compound in 0.2 ml of tetrahydrofuran on a 20 cm² substrate surface. The substrate was polyester film with an aluminum layer over a methylcellulose sublayer of about 0.4 µm thickness.

Ionization potential was measured as described in Grigalevicius et al., "3,6-Di(N-diphenylamino)-9-phenylcarbazole and its methyl-substituted derivative as novel hole-

transporting amorphous molecular materials," Synthetic Metals **128** (2002), p. 127-131, incorporated herein by reference. In particular, each sample was illuminated with monochromatic light from the quartz monochromator with a deuterium lamp source. The power of the incident light beam was $2\text{-}5\cdot10^{-8}$ W. The negative voltage of -300 V was supplied to the sample substrate. The counter-electrode with the 4.5×15 mm² slit for illumination was placed at 8 mm distance from the sample surface. The counter-electrode was connected to the input of the BK2-16 type electrometer, working in the open input regime, for the photocurrent measurement. A $10^{-15} - 10^{-12}$ amp photocurrent was flowing in the circuit under illumination. The photocurrent, I, was strongly dependent on the incident light photon energy $h\nu$. The $I^{0.5}=f(h\nu)$ dependence was plotted. Usually the dependence of the square root of photocurrent on incident light quanta energy is well described by linear relationship near the threshold [see references "Ionization Potential of Organic Pigment Film by Atmospheric Photoelectron Emission Analysis," Electrophotography, 28, Nr. 4, p. 364 (1989) by E. Miyamoto, Y. Yamaguchi, and M. Yokoyama; and "Photoemission in Solids," Topics in Applied Physics, 26, 1-103 (1978) by M. Cordona and L. Ley, both of which are incorporated herein by reference]. The linear part of this dependence was extrapolated to the $h\nu$ axis and I_P value was determined as the photon energy at the interception point. The ionization potential measurement has an error of ± 0.03 eV. The ionization potential values are given in Table 2.

Table 2 - Ionization Potential

Compound	I_P (eV)
2	5.65
3	5.70
4	5.29
5	5.25